

ILLUMINATING DEVICE WITH POLARIZATION RECYCLING
IN A DOUBLE PRISM

5 The invention relates to a system for illuminating an object and notably to a system requiring illumination using polarized light. The invention is notably applicable in liquid-crystal projection and backprojection systems.

10 Liquid crystal cells that allow light to be modulated for displaying images need to be illuminated by means of polarized light in order to operate. When using a source of unpolarized light, a means for using the two polarizations of the light must be provided in order to avoid losing 50% of the luminous power emitted
15 by the illuminating source, which does not take account of the losses by absorption in the polarizers.

A system described in the patent US 5 784 181 is notably known that provides two prisms whose cross sections are right-angled triangles and which sandwich
20 a holographic polarizing beam splitter between faces each containing one side of the right angle of the right-angled triangles. The other faces of the prisms containing the other side of the right angle of the right-angled triangle are situated on one and the same
25 plane and are used as exit faces. A source of unpolarized light emits a beam that illuminates a face forming the hypotenuse of a prism in a direction parallel to the cross section of the prism. The light reaches the holographic splitter which transmits light
30 with a first polarization to the exit face of a prism which contains a device for transforming this first polarization into a second polarization, whereas it reflects light with a second polarization to the exit face of the other prism which does not contain a
35 polarization conversion device. Holographic devices are associated with the exit faces that allow the directions of the beams, which have the same polarization downstream of the exit faces, to be

as filed

changed, so as to make the beams parallel in order that they illuminate a liquid crystal cell in one and the same direction.

However, in such a system, the holographic devices must be illuminated or "read" under a Brewster angle of incidence of around 45° . Hence, they have difficulty operating under an incidence of around 30° . This system therefore has the drawback, since it uses holographic devices, of requiring an illuminating beam with a low divergence. Furthermore, this system is only effective within a limited spectral band. Typically, each holographic device is only effective within one primary spectral band (red, green or blue) of visible light.

The document US 5 716 122 describes a polarization recycling system also using two prisms separated by a polarizing beam splitter of the thin-film multilayer type (see columns 4 and 5 - column 17, lines 42-49); according to this document, the incident beam is not necessarily only composed of parallel rays, but may include nonparallel components (column 19, lines 15-17); however, the angles of incidence on the polarizing beam splitter that are mentioned in this document are in the range between 45° and 38° , which represents an undesirable limitation when the incident beam has a wide divergence, notably higher than or equal to 5° on either side of the general direction of this beam.

Other documents, such as US 4 575 191, US 4 161 349, US 3 987 299, describe systems known as Koesters systems which also provide two prisms whose cross sections are right-angled triangles and which here sandwich a color splitter between the faces each containing one side of the right angle of the right-angled triangles.

The aim of the invention is therefore to provide a solution to the aforementioned drawbacks.

The invention therefore relates to an illuminating device comprising an optical source emitting an unpolarized light beam. A polarizing beam splitter is included between first faces of a first and
5 of a second transparent prism. These prisms each have a second exit face both situated within one and the same plane. The first faces and the second faces of each prism are perpendicular. The light beam penetrates into the first prism through a third face of this prism and
10 reaches the polarizing beam splitter that transmits the light with a first polarization direction and that reflects the light with a second polarization direction. Furthermore, the polarizing beam splitter comprises a grid polarizer situated between the first
15 faces of the first and of the second prism. In addition, the light transmitted by the polarizing beam splitter is transmitted to a third face of the second prism that reflects it toward said second exit face of the second prism, whereas the light reflected by the
20 polarizing beam splitter is transmitted to said third face of the first prism that reflects it toward said second exit face of the first prism. Thanks to the use of a grid polarizer, the polarization can be effectively separated over a wide range of angles of
25 incidence; this also allows the third face of the first prism to be illuminated by a beam originating from the source with a wide divergence, notably greater than or equal to 5° on either side of the average direction of the beam; preferably, this divergence nevertheless
30 remains less than or equal to 10° on either side of the average direction of the beam.

Advantageously, the system comprises a polarization rotator device associated with one of said second exit faces of the prisms. This device then
35 allows the same polarization direction to be obtained downstream of two exit faces.

Advantageously, said grid polarizer is formed on the first face of the first prism or on the first face of the second prism.

An air gap is advantageously provided between,
5 on the one hand, the grid polarizer and said first face of the first or of the second prism on which it is formed and, on the other, the other first face of the second or of the first prism (2 or 1), respectively, situated facing it. This air gap can be used for
10 cooling the system.

According to one embodiment of the system of the invention, the non-right angles of the prisms are substantially equal to 60° opposite the first faces and to 30° opposite the second faces, and the average
15 direction of the light beam F1 is substantially perpendicular to the third face of the first prism as it penetrates into this prism. Such a geometrical configuration ensures that the average direction of the beam passing through the second exit face of the first
20 prism and the average direction of the beam passing through the second exit face of the second prism are substantially parallel to one another and perpendicular to these second faces. This configuration is therefore designed so that the optical axes of the beams emerging
25 from the exit faces are parallel. It should also be noted that, downstream of the splitter, by way of this geometric configuration, the optical paths of the two separate beams are then approximately identical, a fact which is very advantageous for the application of this
30 device to the illumination of a projection system imager.

Preferably, the index of the material of the prisms is less than or equal to 1.5, which allows angles of incidence less than 60° on the grid polarizer
35 to be obtained, even for a wide divergence of the beam.

Advantageously, the system may comprise a light integrating device having an entry face that is optically coupled to said second exit faces of the

prisms and that, receiving the beams reflected by the third faces of the prisms, delivers a beam through an exit face whose illumination is substantially homogeneous over this face. For this purpose, a rod
5 integrator is advantageously used.

Advantageously, the light beam emitted by the source is an uncollimated beam such that the envelopes of the beams received by the light integrator device are such that all of the beams penetrate into the
10 integrator device.

The various aspects and features of the invention will become more clearly apparent in the description that follows and in the appended drawings which show:

15 figure 1, a general example of an illuminating system according to one embodiment of the invention,

figure 2a and 2b, a more detailed example of an illuminating system according to one embodiment of the invention,

20 figure 3, an example of application of the invention to a projection system according to the invention.

An example of an illuminating system according to the invention will therefore be described with
25 reference to figure 1.

This system comprises a light source S emitting an unpolarized light beam F1 toward two prisms 1 and 2. These two prisms have cross sections in the plane of incidence of the beam F1 and take the form of right-
30 angled triangles. Two sides 10 and 20 of the right-angled corners of the prisms sandwich a polarizing beam splitter device 3. The two other faces 11 and 21 of the right-angled corners of the prisms are situated in one and the same plane. These faces 11 and 21 will serve as
35 exit faces of the prisms.

The face 12 of the prism 1 containing the hypotenuse of the cross section of the prism 1 will serve as the entry face of the system.

The beam F1 has an angle of incidence on the face 12 that allows it to enter the prism 1. Advantageously, the beam F1 is substantially perpendicular to the face 12.

5 According to the invention, the polarizing beam splitter is a grid polarizing beam splitter; in order to notably allow its cooling, an air gap 4 is provided here in between the splitter and the prism 1. For an appropriate angle of incidence of an incident ray, the
10 light polarized in one direction will not (or hardly) be influenced by the polarizing beam splitter, whereas the light polarized in a perpendicular direction will be reflected by the polarizing beam splitter.

 The beam F1 therefore reaches the polarizing
15 beam splitter 3 that transmits the light polarized in one direction toward the face 22 of the prism 2, which contains the hypotenuse of the cross section of this prism, and that reflects, toward the face 12 of the
20 prism 1, the light polarized in a direction perpendicular to the first direction. More precisely, it transmits the light whose direction of polarization is perpendicular to the direction of the elements of the polarization grid 3, and it reflects the light
25 whose polarization direction is parallel to these elements.

 A description of a grid polarizing beam splitter will be found in the document US 6 122 103. Preferably, the orientation of the polarizer is such that the grid elements are perpendicular to the plane
30 of figure 1. In this case, the polarization S will be reflected. This reflection will occur toward the face 10 and the light received on the face 10 must normally be transmitted toward the face 12 of the prism 1. This is the reason why, in the exemplary embodiment in
35 figure 1, in order to avoid that the light or a part of the light be reflected between the polarizer 3 and the face 10 of the prism 1, this face 10 will advantageously receive an anti-reflective coating.

In the exemplary embodiment in figure 1, the polarizing beam splitter is applied to the face 20 of the prism 2. However, it is clear that if it is applied to the face 10 of the prism 1, then it is the face 20 of the prism 2 that would advantageously receive an antireflective coating.

The face 22 of the prism 2 reflects the light transmitted toward the face 21. This reflection occurs either by total internal reflection, or by total reflection on the face 22 with a reflective coating (for example metallic).

The face 12 reflects by total internal reflection the light reflected by the polarizing beam splitter toward the face 11.

Advantageously, the angles of the prisms and the angle of incidence of the beam F1 on the face 12 are chosen so that the directions of the two exit beams FS1 and FS2 are parallel.

Figure 2a shows a more detailed exemplary embodiment of the system in figure 1.

In order that the direction of the beams FS1 and FS2 are parallel, the prisms 1 and 2 have their faces 11 and 12, on the one hand, and 21 and 22, on the other, forming angles of 60° . In addition, the direction of the beam F1 is preferably substantially normal to the plane of the entry face 12. The direction of the beam F1 therefore preferably forms an angle of incidence of 30° with respect to the plane of the face 10 (see figure 2b).

Thus, as previously indicated, if an air gap is provided in between the polarizer and the face 10 of the prism 1, and if the prisms are made of glass, for example of BK7 with index of around 1.5, the angle of incidence of the direction of the beam F1 on the polarizing beam splitter 3 is then around 48° . This therefore implies, as is shown in figure 2b, that a light ray of the beam F1 forming an angle of incidence of 30° with the face 10, will form an angle of

incidence of around 48° on the plane of the polarizing beam splitter 3.

The advantage in using a grid polarizing beam splitter is that it has a very high separation efficiency over a wide range of angles of incidence, which here allows it to be illuminated by an uncollimated beam F1, notably exhibiting a large divergence that is greater than or equal to 5° on either side of its average direction. An optimum efficiency for this splitter is obtained for angles of incidence of the rays of the beam F1 in the range between 0° and 60° . With an angle of incidence of 48° , it is therefore within the optimal range of operation.

In addition, if the light beam emitted by the source is uncollimated, the use of a grid polarizing beam splitter will also split the light of a beam whose angular divergence is distributed either side of an average direction having this angle of incidence of around 48° with the plane of the grid polarizing beam splitter, while at the same time exhibiting a high separation efficiency. In practice, the beam divergence could be acceptable up to 9 or 10° on either side of the average direction of the beam. The configuration will therefore be that in which the grid splitter operates with angles of incidence of the incident light of, for example, between $48^\circ + 10^\circ$ and $48^\circ - 10^\circ$. This configuration will therefore allow the polarizing beam splitter to be operated with an optimal efficiency.

In order to obtain an illuminating system delivering an illuminating beam polarized in only one direction, a polarization rotator 6 is provided that is associated with only one of the exit faces of the prisms, the face 11 for example. This polarization rotator therefore makes the direction of polarization of the beam reflected by the face 12 of the prism 1 rotate by 90° .

Figure 3 shows a system in which a light integrator device 7 is provided. This device is coupled

to the exit faces 11 and 21 of the prisms 1 and 2 so as to allow the coupling of all of the light reflected by the faces 12 and 22.

Preferably, as is shown in figure 3, the light
5 beam emitted by the source S is focused close to the entry face 70 of the integrator device 7. The integrator device delivers via its exit face 71 a relatively homogeneous beam that allows an object 8 to be illuminated in a uniform manner. In the case of a
10 projection apparatus, this object is a spatial light modulator which modulates the received light and allows an image displayed on the spatial light modulator to be projected onto a screen.

The grid polarizing beam splitter is formed on
15 the face 20 of the prism 2 in the form of an array of bands of material that is reflective for the light emitted by the source S. This material can be a metal such as aluminum. The pitch of the bands is, for example, of the order of a few tens of nanometers and
20 the width of each band is a few nanometers.

Such an illuminating system has the advantages of operating with an uncollimated beam emitted by the source and of delivering a homogeneous illumination at the exit of the integrator device. In addition, such a
25 system operates over a wide range of wavelengths and especially in the visible range.